

Determinants of sustainable integrated cattle-rice farming systems in Indonesia

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Abstract. Malik A, Setiadi A, Mariyono J, Sutaryo S. 2026. Determinants of sustainable integrated cattle-rice farming systems in Indonesia. *Asian J Agric* 10 (1): g100168. <https://doi.org/10.13057/asianjagric/g100168>. The Agricultural System Integrated Cattle-Rice Farming (ASICRF) represents a strategic approach to promoting sustainable agricultural development through the optimization of local resource utilization and the improvement of farm performance. This study employs a Structural Equation Modeling-Partial Least Squares (SEM-PLS) approach to examine the determinants of ASICRF sustainability within a performance-mediated framework. Data were collected from 280 farmers practicing ASICRF across four major rice and cattle (*Bos indicus*) production districts in Central Java Province, Indonesia. In the proposed model, sustainability is specified as the endogenous variable, system performance as the mediating variable, and technical production practices, farm economics, institutional systems, and environmental and resource factors as exogenous variables. The results indicate strong explanatory power, with R^2 values of 0.709 for system performance and 0.742 for system sustainability. Technical production practices, institutional systems, and environmental and resource factors significantly and positively affect system performance, with environmental and resource factors exerting the strongest influence. In contrast, farm economics does not significantly affect system performance. System performance is confirmed as a key mediating variable linking upstream determinants to sustainability outcomes. These findings suggest that sustainability in ASICRF is closely associated with improvements in overall system performance rather than relying solely on technical or economic inputs. In the context of ASICRF, sustainability may reflect farmers' perceived ability to continuously adopt the system, use resources more efficiently, maintain stable productivity, and generate long-term farm income. However, these results should be interpreted with caution because they are based on self-reported perceptual data from ASICRF farmers selected using non-probability sampling methods. Overall, the study provides empirical insight that may inform the design of context-specific policies and development strategies aimed at strengthening the long-term sustainability of integrated farming systems.

Keywords: Circular agriculture, environmental resource efficiency, integrated farming systems, institutional capacity, SEM-PLS

INTRODUCTION

Livestock and food crop production are important components of food security and sustainable agricultural development. However, farm productivity and efficiency are influenced not only by technical factors but also by economic, institutional, social, and environmental aspects. Therefore, a production system approach is needed that is able to integrate these various components synergistically. In this context, the Agricultural System Integrated Cattle-Rice Farming (ASICRF) is a relevant approach to integrating rice and livestock cultivation into one integrated production system. This integration allows the use of rice straw as animal feed and animal manure as organic fertilizer, thereby creating an efficient and environmentally friendly production cycle (Carlos et al. 2020; Benauli et al. 2023; Swastika et al. 2024).

Various studies show that the implementation of ASICRF can increase productivity, reduce production costs, improve soil quality, as well as strengthen the economic resilience of farming households by reducing

dependence on external inputs (Thornton and Herrero 2015; Paul et al. 2022; Rhofita 2022; Swastika et al. 2024). This system also supports the principles of circular agriculture through the optimization of biomass recycling and resource utilization efficiency (Herrero et al. 2010; Ryschawy et al. 2012; Kurniati et al. 2021; Shanmugam et al. 2024).

In addition, ASICRF contributes to environmental sustainability and resilience to climate change by reducing waste and external input use (Sekaran et al. 2021; Vall et al. 2023; Bhagat et al. 2024). This strategy improves productivity and efficiency while simultaneously reducing greenhouse gas emissions and reinforcing national food system resilience (Hikmah et al. 2024; Wang et al. 2024). However, the implementation of ASICRF still faces various obstacles, such as limited access to capital, technical knowledge, markets, and institutional support. This shows that the sustainability of the system is not only determined by technical factors, but by complex interactions among various economic, institutional, and

environmental factors (Nababan and Regina 2021; Vall et al. 2023; Hikmah et al. 2024).

To understand this multidimensional relationship, an analytical approach is needed that is able to capture the interactions between technical, economic, institutional, and environmental factors, and their relationship to performance and system sustainability. Structural Equation Modeling-Partial Least Squares (SEM-PLS) is an appropriate method because it is capable of analyzing the causal relationships between latent constructs simultaneously and providing robust estimates for survey data (Ghozali and Latan 2015; Khan et al. 2019; Hair et al. 2021; Sarstedt and Liu 2024).

Although the literature on integrated farming systems continues to grow, previous SEM-based studies are still limited in explaining how multidimensional determinants interact within a single integrated framework to influence sustainability through system performance. Most studies generally focus on direct effects, such as farmers' behavior and business performance in integrated paddy-beef cattle systems (Rahayu et al. 2023), productivity-related social factors (Relawati et al. 2019), social innovation and rural well-being in integrated farming systems (Arifa and Fahmi 2025), or adoption decisions in crop-livestock integration (Widarni et al. 2020; Yuhendra et al. 2022), thereby limiting understanding of how these dimensions interact to shape operational performance and long-term sustainability simultaneously. As a result, the mediating role of system performance has not been widely examined in integrated farming studies. Institutional factors are also generally not explicitly modelled as latent constructs within SEM-based integrated farming studies. Therefore, existing studies have not comprehensively integrated multidimensional determinants, institutional constructs, and mediation mechanisms into a unified SEM-PLS framework for explaining sustainability in integrated cattle-rice farming systems.

This study aims to address this gap by developing an integrated SEM-PLS framework that analyzes the direct and indirect influences of technical, economic, institutional, and environmental aspects on sustainability through system performance in the context of ASICRF. System performance is positioned as a key mediating variable that reflects operational effectiveness, including productivity, efficiency of input use, and profitability.

Accordingly, the research hypotheses are formulated as follows:

H1a: Technical production practices significantly affect ASICRF performance.

H1b: Technical production practices significantly affect ASICRF sustainability.

H2a: Farm economics significantly affect ASICRF performance.

H2b: Farm economics significantly affect ASICRF sustainability.

H3a: Institutional systems significantly affect ASICRF performance.

H3b: Institutional systems significantly affect ASICRF sustainability.

H4a: Environmental and resource factors significantly affect ASICRF performance.

H4b: Environmental and resource factors significantly affect ASICRF sustainability.

H5: ASICRF performance significantly affects ASICRF sustainability.

MATERIALS AND METHODS

Data collection and sampling method

This research was conducted in four districts in Central Java Province, Indonesia, which are centers of rice production and livestock development: Sragen, Karanganyar, Boyolali, and Sukoharjo (BPS-Statistics Jawa Tengah Province 2024). Data collection was conducted in February-March 2025, based on production activities during the first planting season (October/November 2024 to January/February 2025).

A total of 280 farmers participated in this study, which was deemed sufficient for SEM-PLS analysis. The study population consisted of rice-farming households that also raised beef cattle in four research districts in Central Java Province, Indonesia. Sample selection was conducted using a modified multi-stage random sampling technique to improve representativeness and statistical accuracy. In the first stage, districts were purposively selected based on their status as major rice and beef cattle production centers. The selected districts included Karanganyar, Boyolali, Sukoharjo, and Sragen Districts. In the second stage, sub-districts were selected using simple random sampling from areas implementing the ASICRF. In the third stage, villages were selected proportionally based on the rice harvested area. The sample size was determined using the Slovin formula with a 10% margin of error, resulting in a total of 280 respondents. In the final stage, respondents were selected through simple random sampling using verified farmer lists obtained from the Agricultural Extension Centers (*Balai Penyuluhan Pertanian/BPP*) in each selected village. Table 1 presents the distribution of respondents by district. Primary data were collected through structured face-to-face interviews.

Research instrument and measurement

The determinants of ASICRF sustainability were analyzed using SEM-PLS via SmartPLS 4. This method combines factor analysis and regression, thus allowing the estimation of the relationship between latent constructs in a systematic and simultaneous manner without requiring the assumption of normal distribution (Hair et al. 2019; Michels et al. 2021; Setiabudhi et al. 2025). SEM-PLS is a causal-predictive approach and is widely used in agricultural and environmental research (Sarstedt and Liu 2024). The analysis consists of a measurement model and a structural model (Irwan and Adam 2015; Civelek 2018).

The conceptual framework includes four exogenous constructs, namely Technical Production Practices (X1), Farm Economics (X2), Institutional Systems (X3), and Environmental and Resource Factors (X4); one mediating

construct, ASICRF Performance (Y1); and one endogenous construct, ASICRF Sustainability (Y2) (Figure 1).

Data were collected using a structured questionnaire consisting of closed-ended statements measured on a five-point Likert scale, ranging from strongly disagree (1) to strongly agree (5), to assess farmers' perceptions, evaluations, and levels of agreement regarding the implementation of ASICRF. Table 2 presents the latent constructs, measurement indicators, corresponding measurement codes, and literature sources used in the SEM-PLS analysis. The indicators were adapted from previous studies and contextualized to reflect the characteristics of ASICRF.

All latent constructs in this study were specified as reflective measurement models, as the observed indicators are conceptualized as manifestations of the underlying constructs rather than as defining components. Changes in the latent constructs are therefore expected to be reflected in corresponding changes across all indicators. This specification is appropriate given that the indicators are theoretically interchangeable, expected to covary, and

evaluated using reliability and validity criteria commonly applied in reflective measurement models (Hair et al. 2019, 2021). Furthermore, the indicators were designed to capture farmers' overall perceptions regarding each construct and were theoretically expected to change simultaneously as the underlying latent construct changes.

To maintain conceptual clarity, system performance (Y1) and system sustainability (Y2) are distinguished as two interrelated but distinct constructs. Performance reflects short- to medium-term operational results, such as productivity, input-use efficiency, and profitability of farming. On the other hand, sustainability reflects long-term outcomes, which include economic feasibility, social acceptance, resilience, and sustainability of system implementation. This difference is based on time orientation and analytical function, where performance acts as an intermediate outcome leading to sustainability. Thus, performance represents operational effectiveness, whereas sustainability reflects the long-term continuity and resilience of the integrated farming system.

Table 1. Distribution of respondents by district

District	Sub-district	Village	Population size*	Number of respondents	Percentage of total respondents (%)
Karanganyar	Gedongsari	Kranggan and Karangturi	240	71	25.36
Boyolali	Andong	Pakang and Kedungdowo	202	67	23.93
Sukoharjo	Polokarto	Polokarto and Genengsari	252	72	25.71
Sragen	Karangmalang	Puro and Palem Gadung	228	70	25.00
Total			922	280	100.00

Note: *: The population consisted of farmers who raised beef cattle and cultivated irrigated rice fields

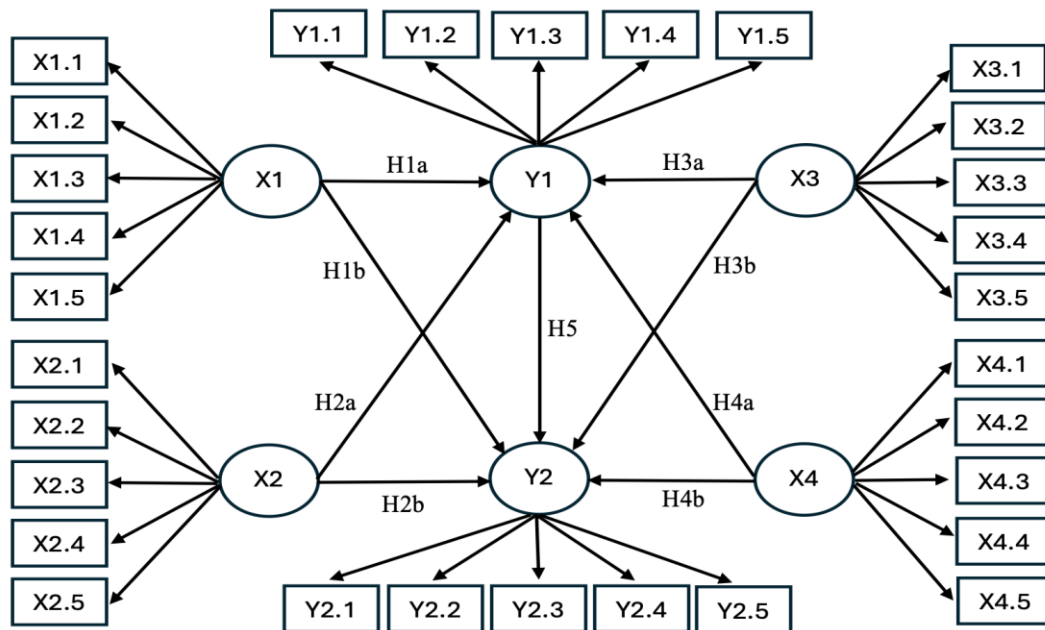


Figure 1. Conceptual research model

Table 2. Latent constructs, indicators, and measurement codes used in the SEM-PLS analysis

Latent constructs	Indicators	References	Code
Technical production practices (X1)	Rice straw from rice fields is used as cattle feed.	Mukhlis et al. (2018); Sekaran et al. (2021)	X1.1
	Cattle manure is used as organic fertilizer for rice crops.	Mukhlis et al. (2018); Sekaran et al. (2021)	X1.2
	The rice cultivation technology used is in accordance with the rice–cattle integration system.	Sekaran et al. (2021)	X1.3
	Cattle feed is available throughout the year.	Duguma and Janssens (2021)	X1.4
	Cattle health management is carried out routinely and in a planned manner.	Capper and Williams (2023)	X1.5
Farm economics (X2)	The rice-cattle integration system reduces the cost of purchasing feed and fertilizer.	Sekaran et al. (2021)	X2.1
	The rice-cattle integration system increases my household income.	Shanmugam et al. (2024)	X2.2
	Rice-cattle farming provides more than one source of income.	Shanmugam et al. (2024)	X2.3
	Income from rice and cattle farming is relatively stable throughout the year.	Shanmugam et al. (2024)	X2.4
	The crop-livestock integration system provides added value to rice and livestock by-products.	Ninawe (2025)	X2.5
Institutional systems (X3)	The concept and benefits of rice-cattle integration are well understood.	Sekaran et al. (2021)	X3.1
	Farmers have sufficient experience in cattle farming and rice cultivation.	Mponji et al. (2024)	X3.2
	Farmer/livestock groups actively support the implementation of rice–cattle integration.	Sannou et al. (2023)	X3.3
	Extension services and technical assistance are easily accessible.	Onesmus (2024)	X3.4
	Cooperation among farmers in implementing the integrated system is very good.	Saleh and Ehlers (2025)	X3.5
Environmental and resource factors (X4)	Agricultural and livestock waste is utilized and managed optimally.	Mukhlis et al. (2018)	X4.1
	The use of organic fertilizer increases the fertility of rice field soils.	Domínguez-Hernández et al. (2025)	X4.2
	The rice–cattle integration system reduces the use of chemical fertilizers.	Domínguez-Hernández et al. (2025)	X4.3
	The integrated system reduces environmental pollution.	Ninawe (2025)	X4.4
	The system is able to adapt to climate change.	Peterson et al. (2020)	X4.5
ASICRF performance (Y1)	Rice productivity has increased since the implementation of the integration system.	Sekaran et al. (2021)	Y1.1
	Cattle productivity and body weight have increased.	Sekaran et al. (2021); Domínguez-Hernández et al. (2025)	Y1.2
	The use of production inputs has become more efficient.	Domínguez-Hernández et al. (2025)	Y1.3
	Farming profits have increased.	Shanmugam et al. (2024)	Y1.4
	The integration system operates effectively.	Martikainen (2025)	Y1.5
ASICRF sustainability (Y2)	The rice-cattle integration system is economically viable in the long term.	Sekaran et al. (2021)	Y2.1
	The system demonstrates social sustainability through farmer acceptance and participation.	Saleh and Ehlers (2025)	Y2.2
	The rice-cattle integration system is accepted as a sustainable and environmentally friendly technology.	Ninawe (2025)	Y2.3
	The system is resilient to farming risks.	Sekaran et al. (2021)	Y2.4
	Farmers intend to continue and expand the system.	Saleh and Ehlers (2025)	Y2.5

Although sustainability can be conceptually viewed as a formative construct due to its multidimensional nature, this research uses a reflective approach because the indicators are expected to be mutually correlated and represent an integrated latent construct. This approach is in accordance with SEM-PLS guidelines and is considered appropriate for capturing farmers' perceptions of sustainability. Changes in perceived sustainability are therefore assumed to influence all sustainability indicators simultaneously, including long-term economic feasibility, social acceptance, resilience, environmental appropriateness, and continuity intention. In addition, the indicators demonstrated conceptual interrelatedness and high internal consistency, supporting

the appropriateness of reflective specification in accordance with SEM-PLS literature (Hair et al. 2019, 2021).

Each construct and its indicators were consistently coded across the questionnaire, tables, and structural model, with exogenous constructs labelled X1–X4, the mediating construct labelled Y1, and the endogenous construct labelled Y2, to ensure clarity and consistency in model specification and reporting.

Data analysis

SEM-PLS analysis was conducted by assessing the measurement model (outer model) and the structural model

(inner model) to confirm the overall adequacy of the proposed model (Ghozali 2014).

Measurement model evaluation

The measurement model was evaluated to ensure the validity and reliability of the constructs. Convergent validity was tested using outer loadings and Average Variance Extracted (AVE), with respective thresholds of 0.70 and 0.50 (Ghozali 2014). Discriminant validity was tested using the Heterotrait-Monotrait (HTMT) ratio, with values below 0.90 indicating adequate construct differentiation (Henseler et al. 2015). Construct reliability was assessed through composite reliability and Cronbach's alpha, with values above 0.70 considered to meet the required criteria (Ghozali 2014; Hair et al. 2019).

Common method bias assessment

Given that all constructs were measured using self-reported Likert-scale items collected from the same respondents in a single survey session, the potential risk of Common Method Bias (CMB) was considered. Several procedural remedies were applied during data collection to mitigate this risk, including assuring respondent anonymity, emphasizing that there were no right or wrong answers, and using neutral and clearly worded questionnaire items.

As a post-hoc diagnostic, Variance Inflation Factors (VIFs) were examined to assess potential collinearity effects. Following general SEM-PLS guidelines, VIF values below 5 indicate the absence of serious multicollinearity (Hair et al. 2019). Although the conservative threshold of 3.3 suggested by Kock (2015) for detecting common method variance was not strictly met for all indicators, all VIF values remained below 5. This suggests that while common method variance cannot be entirely ruled out, it is unlikely to critically bias the estimated structural relationships. Nevertheless, because all variables were measured using self-reported perceptual responses collected from the same respondents in a single survey session, some degree of shared-method variance and perceptual reinforcement among constructs may still exist. Therefore, the structural relationships should be interpreted cautiously as perception-based associations rather than purely objective causal relationships.

Structural model evaluation

The structural model was assessed to examine causal relationships among latent constructs and the predictive strength of endogenous constructs. Model evaluation included multicollinearity, coefficient of determination (R^2), effect size (f^2), predictive performance, and path coefficient significance (Hair et al. 2019; Sarstedt and Liu 2024). Multicollinearity was tested using the VIF, with values below 5, or conservatively below 3.3, indicating acceptable levels of collinearity among exogenous constructs (Kock 2015; Hair et al. 2019). The coefficient of determination (R^2) assessed the proportion of variance in endogenous constructs explained by exogenous constructs, with values of 0.19, 0.33, and 0.67 representing weak, moderate, and strong explanatory power, respectively.

Effect size (f^2) quantified the contribution of each exogenous construct to the endogenous variables, with values of 0.02, 0.15, and 0.35 representing small, medium, and large effects (Cohen 1988; Hair et al. 2019). Predictive performance was assessed using the PLS-Predict procedure implemented in SmartPLS 4. This approach evaluated out-of-sample predictive power by comparing prediction errors between the PLS model and a linear benchmark model. Path coefficients and their significance levels were determined through bootstrapping procedures implemented in SmartPLS 4.

RESULTS AND DISCUSSION

Respondent characteristics

The ASICRF system is dominated by older farmers, with 73.93% of respondents aged over 50 years, including 41.07% aged over 60 years. Although this reflects high levels of experience, the low participation of young farmers (8.57%) indicates weak regeneration, which potentially limits the long-term viability and sustainability of ASICRF. This condition may also create challenges related to labor continuity, technology adoption, and long-term knowledge transfer within integrated farming systems. Most of the respondents have primary to secondary education, which indicates limited formal capacity, but this is likely offset by extensive practical experience. Male farmers dominate system management (95%), which indicates a concentration of decision-making roles. Most respondents also have long farming experience, with 63.21% having more than 20 years of experience, which strengthens the role of accumulated knowledge in system implementation. The average income reaches IDR 28.27 million per year, with most respondents falling into the middle- to high-income categories. However, this value is indicative because it can be influenced by seasonal variations in production conditions and market prices.

Results of measurement model evaluation

The results of the analysis show that all constructs (X1, X2, X3, X4, Y1, and Y2) meet the validity and reliability criteria (Table 3). The outer loading values range from 0.711 to 0.914, which exceed the 0.70 threshold, thus indicating adequate indicator reliability (Henseler et al. 2015; Hair et al. 2019). Indicators with values close to the threshold are retained because of their theoretical relevance and because they do not reduce the quality of the model (Hair et al. 2021). The cross-loading results also show that each indicator has the highest loading on its respective construct, indicating that discriminant validity is achieved.

In the endogenous constructs, namely performance (Y1) and sustainability (Y2), all indicators have loading values above 0.78, with particularly high values for the sustainability construct, which indicates strong internal consistency. Construct reliability is confirmed, with Cronbach's alpha values between 0.883-0.936 and composite reliability values above 0.90, indicating excellent internal consistency (Hair et al. 2019). Convergent validity is also fulfilled, with AVE values

ranging from 0.684 to 0.795, exceeding the threshold of 0.50 (Fornell and Larcker 1981; Hair et al. 2021).

Overall, these results indicate that the measurement model meets the validity and reliability criteria and is therefore suitable for structural model analysis and hypothesis testing (Hair et al. 2019; Sarstedt and Liu 2024).

As shown in Table 4, discriminant validity was achieved, with HTMT values ranging from 0.354 to 0.895, and all values are below the threshold of 0.90 (or 0.85 for conceptually very different constructs) (Henseler et al. 2015; Hair et al. 2021). The highest value is found in the relationship between system performance (Y1) and system sustainability (Y2) (HTMT = 0.895), which is still acceptable considering the conceptual closeness of the two constructs.

This relatively high HTMT value reflects the theoretical relationship between performance as a mediating variable and sustainability as a long-term outcome and does not indicate construct overlap. Nevertheless, the relatively high proximity between Y1 and Y2 may also reflect perceptual interconnectedness because both constructs were measured using self-reported evaluations from the same respondents.

Conceptually, performance represents operational effectiveness in the short to medium term, whereas sustainability reflects broader long-term continuity and resilience. Therefore, although closely related, the two constructs remain analytically distinguishable within the proposed framework. All values within the recommended limits indicate that the constructs can be empirically distinguished and meet discriminant validity criteria. Overall, these results confirm that each construct represents different latent dimensions and support the feasibility of the measurement model for structural analysis (Benitez et al. 2020).

Structural model evaluation results

The structural model demonstrates good quality in terms of multicollinearity, explanatory power, effect size, and predictive ability. VIF values ranged from 1.790 to 4.548, indicating the absence of multicollinearity issues and the stability of the model estimates (Kock 2015; Hair et al. 2019).

Table 3. Results of measurement model evaluation

Constructs	Indicators	Outer loading	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Technical production practices (X1)	X1.1	0.890	0.903	0.906	0.928	0.722
	X1.2	0.870				
	X1.3	0.821				
	X1.4	0.814				
	X1.5	0.851				
Farm economics (X2)	X2.1	0.793	0.907	0.919	0.930	0.726
	X2.2	0.887				
	X2.3	0.863				
	X2.4	0.859				
	X2.5	0.856				
Institutional systems (X3)	X3.1	0.771	0.883	0.892	0.915	0.684
	X3.2	0.715				
	X3.3	0.889				
	X3.4	0.893				
	X3.5	0.852				
Environmental and resource factors (X4)	X4.1	0.823	0.895	0.901	0.923	0.708
	X4.2	0.895				
	X4.3	0.904				
	X4.4	0.860				
	X4.5	0.711				
ASICRF performance (Y1)	Y1.1	0.797	0.889	0.889	0.918	0.693
	Y1.2	0.841				
	Y1.3	0.878				
	Y1.4	0.856				
	Y1.5	0.786				
ASICRF sustainability (Y2)	Y2.1	0.895	0.936	0.937	0.951	0.795
	Y2.2	0.879				
	Y2.3	0.914				
	Y2.4	0.890				
	Y2.5	0.880				

Source: Primary data (analyzed)

The R^2 values of 0.709 (performance) and 0.742 (sustainability) indicate the model's strong ability to explain variations in endogenous constructs (Chin 1998; Hair et al. 2021). Practically, the R^2 value of 0.742 indicates that sustainability can be strongly predicted based on the determinants and system performance, thus providing a clear basis for more targeted sustainability planning and interventions. However, these relatively high R^2 values should also be interpreted cautiously because all constructs were measured using perception-based responses collected from the same respondents in a single survey context. Therefore, some degree of shared-method variance and perceptual reinforcement among constructs may have partially contributed to the model's explanatory power.

The effect size (f^2) values ranged from 0.003 to 0.298, indicating varying contributions among constructs (Cohen 1988). Environmental and resource factors (X4) have the greatest influence on performance (Y1), followed by institutional factors (X3), while farm economics (X2) has a relatively small effect. For sustainability (Y2), system performance (Y1) has the strongest influence, confirming its role as the main mediating variable. The prediction results show positive Q^2 predict values (0.691 for Y1 and 0.655 for Y2) and low prediction errors, which indicate good predictive ability of the model (Shmueli et al. 2019; Sarstedt and Liu 2024).

The results of hypothesis testing and path coefficient estimation are presented in Table 5. Path analysis shows that technical (X1), institutional (X3), and environmental (X4) factors have significant effects on performance (Y1), while the economic factor (X2) does not. For sustainability (Y2), institutional, environmental, and performance factors have significant effects, while technical and economic factors have no direct effects.

The insignificant influence of farm economics indicates that short-term financial incentives are not sufficient to

encourage improvements in system performance. In the context of ASICRF, benefits such as efficiency, improved soil quality, and resource recycling emerge gradually and are not immediately reflected in economic gains. In addition, price fluctuations, limited market access, and high initial costs can weaken short-term economic signals. This suggests that economic benefits play a more long-term role rather than acting as direct drivers of performance. Furthermore, many farmers may prioritize production stability, feed availability, and risk reduction over immediate economic returns when maintaining integrated farming practices. Structural limitations, including limited access to credit, weak bargaining positions, and unstable agricultural commodity prices, may also reduce the ability of economic factors to directly influence perceived sustainability and performance outcomes.

The results of the mediation analysis are presented in Table 6. The findings show that performance (Y1) plays a significant role, fully mediating the influence of technical factors (X1) and partially mediating the influence of institutional (X3) and environmental (X4) factors on sustainability (Y2). Overall, the model demonstrates a strong ability to explain and predict the relationships between constructs. The final structural model and estimated path coefficients are presented in Figure 2.

Table 4. Results of discriminant validity analysis

Constructs	X1	X2	X3	X4	Y1	Y2
X1						
X2	0.741					
X3	0.429	0.413				
X4	0.508	0.354	0.723			
Y1	0.694	0.502	0.770	0.834		
Y2	0.546	0.370	0.738	0.842	0.895	

Source: Primary data (analyzed)

Table 5. Hypothesis testing results

Hypotheses/Paths	β	Sample mean (M)	Standard deviation (STDEV)	t-values	p-values	Conclusion
H1a : X1 → Y1	0.292	0.288	0.062	4.723	p < 0.001	H1a accepted
H1b : X1 → Y2	0.041	0.046	0.055	0.743	p > 0.05	H1b rejected
H2a : X2 → Y1	0.048	0.050	0.045	1.071	p > 0.05	H2a rejected
H2b : X2 → Y2	-0.067	-0.066	0.046	1.449	p > 0.05	H2b rejected
H3a : X3 → Y1	0.287	0.291	0.061	4.725	p < 0.001	H3a accepted
H3b : X3 → Y2	0.143	0.142	0.052	2.785	p < 0.05	H3b accepted
H4a : X4 → Y1	0.410	0.411	0.067	6.096	p < 0.001	H4a accepted
H4b : X4 → Y2	0.313	0.307	0.068	4.581	p < 0.001	H4b accepted
H5 : Y1 → Y2	0.495	0.498	0.079	6.299	p < 0.001	H5 accepted

Source: Primary data (analyzed)

Table 6. Specific indirect effects (bootstrapping results)

Constructs	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics ((O/STDEV))	P values
X1 → Y1 → Y2	0.145	0.142	0.035	4.144	p < 0.001
X2 → Y1 → Y2	0.024	0.024	0.022	1.062	p > 0.05
X3 → Y1 → Y2	0.142	0.145	0.038	3.732	p < 0.001
X4 → Y1 → Y2	0.203	0.206	0.052	3.920	p < 0.001

Source: Primary data (analyzed)

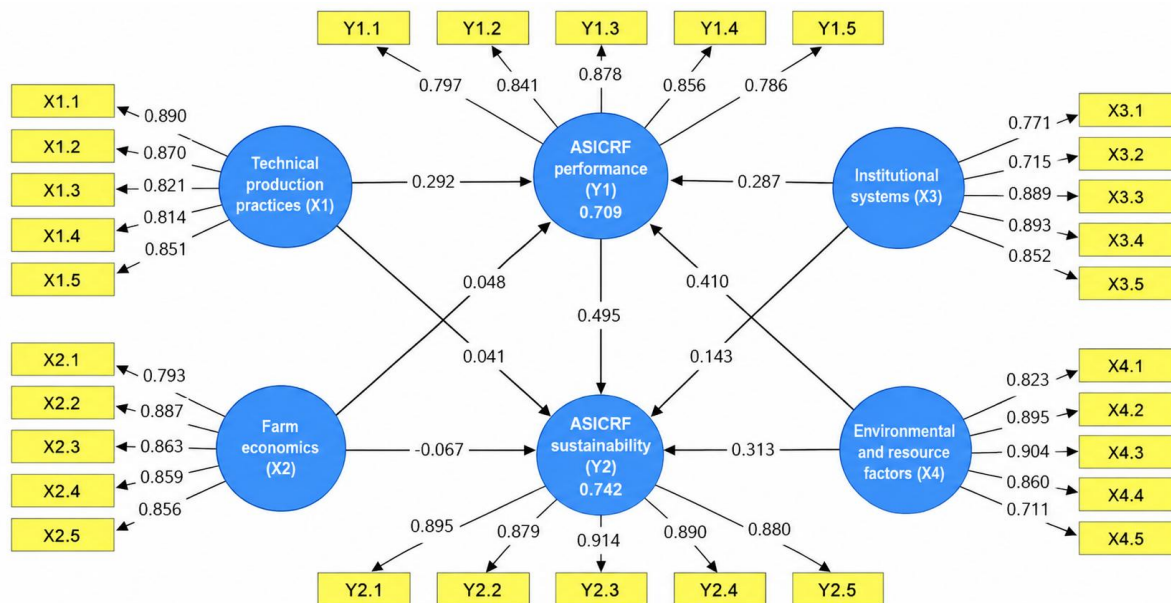


Figure 2. Results of the ASICRF model analysis

Discussion

Determinants of ASICRF performance

The results of the study show that the performance of ASICRF is significantly influenced by technical, institutional, environmental and resource factors, suggesting that the effectiveness of the integration system depends on the interaction between technical efficiency, ecological resource management, and social-institutional support mechanisms. Rather than operating independently, these factors reinforce one another in shaping the overall functionality of the farming system.

Operationally, technical practices such as the use of straw as feed, the application of manure, and integrated crop–livestock management systems contribute not only to higher production efficiency but also to improved internal resource circulation within the farming system. These practices reduce dependence on external agricultural inputs while improving soil fertility, nutrient recycling, and biomass utilization. The integration between crop and livestock components allows waste from one subsystem to become productive inputs for another subsystem, thereby increasing system efficiency and resilience. This finding supports Paramesh et al. (2022), who found that integrated farming systems improve resource efficiency and nutrient cycling. The present study further indicates that technical integration may strengthen long-term adaptive capacity by reducing farmers' vulnerability to input scarcity and rising production costs.

Institutional factors play an important role, especially in the local Javanese context, where farmer groups and extension workers serve as platforms for knowledge exchange, coordination, and access to training and inputs. These institutional arrangements facilitate collective learning processes, strengthen farmers' confidence in adopting integrated practices, and reduce uncertainty associated with system transition. Such conditions allow

more consistent implementation of the integration system and increase farmers' adaptive capacity. This suggests that institutional support functions not merely as administrative assistance, but as a social mechanism that enhances behavioral commitment and continuity of implementation. This finding aligns with Aydin et al. (2024), who emphasized the importance of institutional capacity in supporting agricultural innovation.

Environmental and resource factors are the strongest determinants of performance. This is reflected in the practice of recycling nutrients through the use of livestock manure as fertilizers, reducing chemical inputs, and utilizing agricultural waste as feed. These practices strengthen ecological efficiency while simultaneously lowering production dependency on externally purchased inputs. In addition, improved soil quality and more efficient nutrient utilization may contribute to greater production stability under fluctuating environmental conditions. Consequently, environmentally integrated management not only improves current farm performance but also supports the long-term resilience of the farming system. This finding is consistent with broader integrated farming literature which emphasizes the role of ecological recycling and resource optimization in enhancing sustainable agricultural productivity.

On the other hand, farm economic factors do not have a significant influence on performance. This insignificant influence indicates that short-term financial incentives alone are insufficient to encourage improvements in system performance. In the context of ASICRF, economic benefits such as improved efficiency, soil restoration, and resource recycling tend to emerge gradually and may not be immediately perceived as direct economic gains by farmers. In addition, price fluctuations, limited market access, uncertainty regarding premium prices for environmentally friendly products, and relatively high

initial adjustment costs may weaken the short-term economic motivation to optimize system performance. This finding suggests that the economic contribution of ASICRF may operate more as a long-term reinforcing factor rather than as an immediate driver of performance improvement. The result also reflects structural constraints commonly faced by smallholder farmers, where limited capital capacity and market insecurity reduce the ability to prioritize long-term sustainability investments.

Determinants of ASICRF sustainability

The sustainability of ASICRF is significantly influenced by institutional, environmental and resource factors, as well as system performance. These findings indicate that sustainability is shaped not only by the availability of supporting resources but also by the extent to which the system is able to consistently generate satisfactory operational outcomes for farmers. Sustainability therefore emerges through both direct influences and indirect influences mediated by performance.

Practically, sustainability is achieved when institutional support and resource management are able to maintain production stability, reduce risks, and encourage the sustainable implementation of the system by farmers. Institutional support may strengthen farmers' willingness to sustain the system through extension services, collective coordination, and access to information, while effective resource management contributes to ecological balance and production continuity. Furthermore, farmers are more likely to maintain integrated farming practices when the system demonstrates tangible operational benefits, including input efficiency, stable productivity, and reduced vulnerability to external shocks.

These findings imply that sustainability in ASICRF is closely associated with farmers' perceptions of system viability and continuity. However, because both performance and sustainability were measured using perceptual latent constructs, the possibility of perceptual reinforcement between variables cannot be fully excluded. Farmers who perceive the system as highly sustainable may also evaluate its performance more positively, potentially strengthening the observed relationship between the two constructs. Although the SEM framework supports the theoretical direction of influence, this study acknowledges the potential for endogeneity and reciprocal perception effects that may exist within cross-sectional behavioral assessments.

The mediating role of ASICRF performance

System performance acts as the main mediating variable linking the determining factors to sustainability. Operationally, increased productivity, efficient use of inputs, and business stability enable farmers to maintain and develop integration systems. This suggests that sustainability is not achieved solely through the presence of favorable external conditions, but through the system's ability to transform those conditions into measurable operational outcomes.

The results show that technical factors influence sustainability only through performance (full mediation), while institutional and the environmental factors influence sustainability both directly and indirectly (partial mediation). This finding indicates that technical improvements alone may not automatically ensure sustainability unless they successfully enhance actual farm performance. In contrast, institutional and environmental factors possess broader influences because they also shape farmers' long-term commitment, adaptive behavior, and ecological management practices beyond immediate productivity outcomes. The mediating role of performance therefore confirms that performance functions as the central pathway through which integrated farming systems translate technical capacity, institutional support, and ecological resource management into sustainable agricultural practices.

Limitations

This study has several limitations, including the use of perception-based data, which has the potential to cause common method bias. In addition, the cross-sectional design limits the ability to fully capture dynamic changes in farmers' behavior, system performance, and sustainability over time. Because the study relies on perceptual measurements derived from self-reported responses, the possibility of perceptual bias and reciprocal evaluation between constructs cannot be entirely excluded. Although mitigation efforts have been made, causal interpretations should be made with caution. Further research is recommended using probability sampling methods, longitudinal data, or objective indicators to strengthen causal inference and improve measurement robustness.

In conclusion, the findings highlight that the sustainability of ASICRF is strongly influenced by the interaction between institutional support, resource management, and system performance. Sustainability is not shaped by a single factor, but rather by farmers' ability to maintain system efficiency, stability, and continuity over time.

From a policy perspective, three main priorities should be emphasized. First, strengthening the agricultural extension system is necessary to support knowledge transfer, technical assistance, and adaptive learning among farmers. Second, strengthening farmer institutions and organizations is essential to improve coordination, access to resources, and collective capacity in implementing integrated farming systems. This institutional strengthening can be operationalized through regular extension activities, farmer field schools, collaborative training programs, and stronger farmer group networks that facilitate knowledge sharing and collective decision-making. Third, optimizing resource recycling, such as the utilization of manure and plant waste, should be prioritized to improve efficiency, reduce dependence on external inputs, and strengthen environmental sustainability.

Overall, achieving sustainable integrated farming systems requires the integration of technical support,

institutional capacity, and efficient resource utilization to ensure long-term agricultural sustainability.

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